Check List the journal of biodiversity data

NOTES ON GEOGRAPHIC DISTRIBUTION

Check List 17 (1): 1–6
https://doi.org/10.15560/17.1.1

PENSOFT

First record of the rare bat *Gardnerycteris koepckeae* (Gardner & Patton, 1972) (Chiroptera, Phyllostomidae) in Bolivia

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Abstract
The phyllostomid bat *Gardnerycteris koepckeae* (Gardner & Patton, 1972) was considered endemic to Peru and restrict to only two localities, until it was recently collected in a new locality in Colombia. Now we report *G. koepckeae* for the first time in Bolivia, based on a specimen collected in a well-preserved montane forest inside the Parque Nacional y Área Natural de Manejo Integrado Madidi. The site of capture is at 2280 m, which is the highest elevational record for the species. *Gardnerycteris koepckeae* is a rare species restricted to a fragile ecosystem threatened by mining and other changes in land use.

Keywords
Andes, Identidad Madidi, Koepcke's Hairy-nosed Bat, Madidi National Park, montane forest, Peru, Yungas

Academic editor: Marcelo Nogueira | Received 17 September 2020 | Accepted 3 December 2020 | Published 5 January 2021

Citation: Siles L, Wallace RB (2021) First record of the rare bat *Gardnerycteris koepckeae* (Gardner & Patton, 1972) (Chiroptera, Phyllostomidae) in Bolivia. Check List 17 (1): 1–6. https://doi.org/10.15560/17.1.1

Introduction

The phyllostomid bat *Gardnerycteris koepckeae* (Gardner & Patton, 1972) was originally placed in the genus *Mimon* Gray, 1847, subgenus *Anthorhina* Lydekker, 1891. This species was subsequently placed in a separate genus, *Gardnerycteris* Hurtado & Pacheco, 2014, based on morphological data (Hurtado and Pacheco 2014) and supported by molecular analyses (Hurtado and D'Elía 2018). Soon after the species was described, Koopman (1976) considered it to be a junior synonym of *Gardnerycteris crenulatum* (É. Geoffroy, 1803) and later a highland subspecies (Koopman 1993). More recently, several researchers confirmed the validity of the species (e.g., Simmons 2005), and Hurtado et al. (2014) provided a detailed redescription. Currently, *G. koepckeae* is known from six specimens in total (Fig. 1), five of which were collected from two localities in Peru in 1970 (three specimens), 1971, and 2011 (Gardner and Patton 1972; Hurtado et al. 2014), and one specimen collected in 2012 in Colombia (Morales-Martínez et al. 2020). The known localities for *G. koepckeae* range in elevation from 1080 m in Colombia to 1900 m in Estera Ruana, Ayacucho Department, Peru (Hurtado et al. 2014; Morales-Martínez et al. 2020). Consequently, the species' distribution range is restricted to lower montane forests on the eastern slopes of the Peruvian Central Andes (Hurtado et al. 2014) and the Andean-Amazonian foothills in Colombia (Morales-Martínez et al. 2020). Peruvian legislation considers this species as Critically Endangered (Tello and Mena 2018); however, the IUCN Red List categorizes it as Data Deficient (Velazco and Aguirre 2019). Here we

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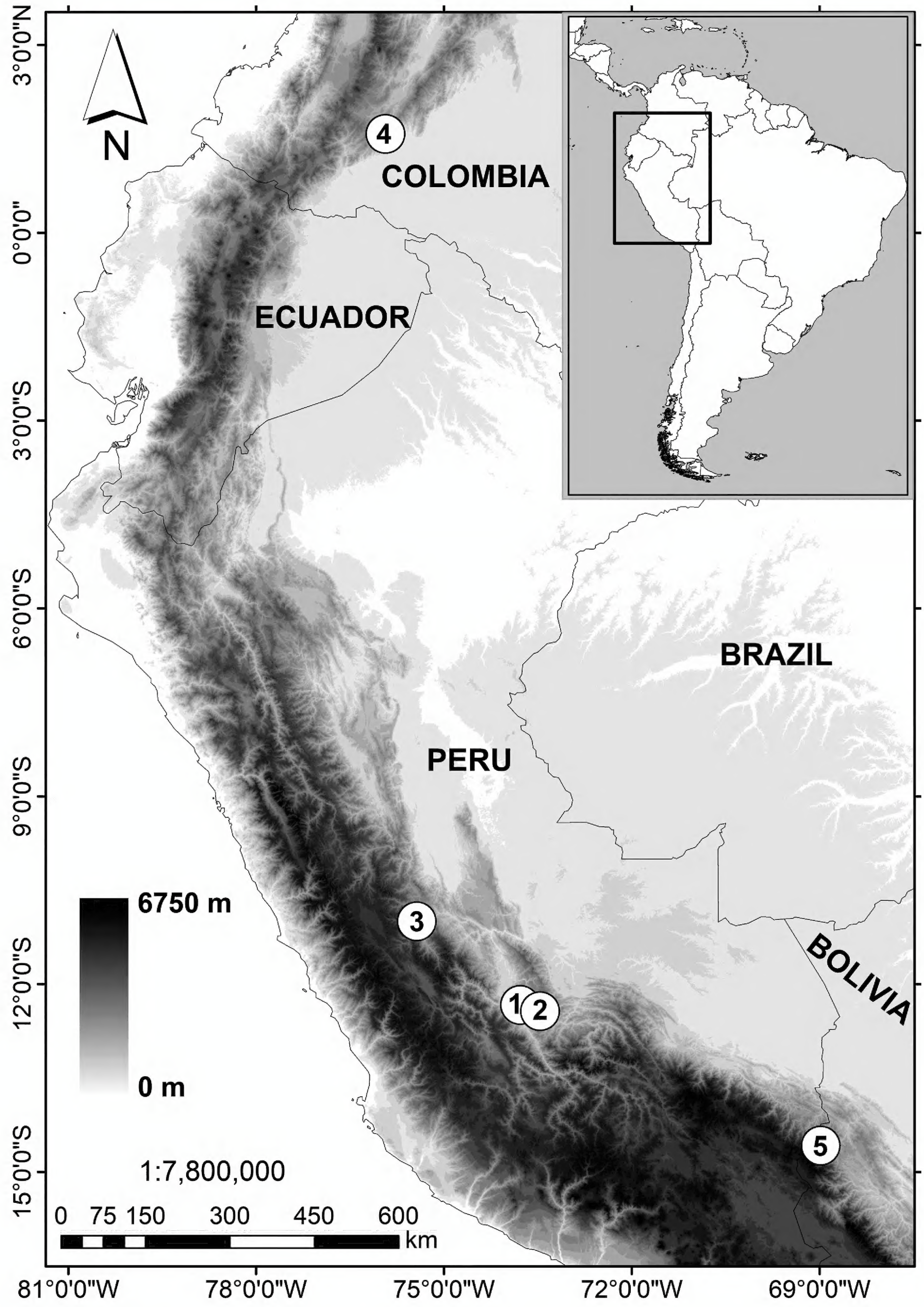

Figure 1. Map of collecting localities of *Gardnerycteris koepckeae*. **1.** Huanhuachayo, Peru; 12.3333°S, 073.7833°W; alt. ca 1660 m; vouchers LSUMZ 16447 holotype and LSUMZ 15675 paratype. **2.** Estera Ruana, Peru; 12.4333°S, 073.4667°W; alt. 1900 m; vouchers LSUMZ 15676 and AMNH 233222 topotype. **3.** Podocarpus Santuario Nacional Pampa Hermosa, Peru; 10.9970°S, 075.4325°W; alt. 1890 m; voucher MUSM 41327. **4.** Belén de Los Andaquíes, Colombia; 01.5800°N, 075.9341°W; alt. 1080 m; voucher MHNUC 2010. **5.** Cargadero PNANMI Madidi, Bolivia; 14.5780°S, 068.9801°W; alt. 2280 m; voucher CBF 8683 (this study).

report a new record of this rare species captured during "Identidad Madidi", a three-year biodiversity project (2015–2017) in which we carried out faunal and floral surveys at 15 study sites across an altitudinal transect within the Parque Nacional y Área Natural de Manejo Integrado Madidi (PNANMI Madidi; in English, Madidi National Park and Natural Area of Integrated Management). We expected to find new distribution records for the park and Bolivia, especially for less studied groups, such as butterflies, plants, and small vertebrates. However, *G. koepckeae* was not in our list of expected bat species due to its rarity and apparent restriction to Peru when our project started (Hurtado et al. 2014).

Methods

As part of the Identidad Madidi initiative (http://www.identidadmadidi.org), we conducted biodiversity surveys from June 2015 to November 2017 at 15 localities throughout the PNANMI Madidi located in the Department of La Paz, Bolivia. The new record reported here was sampled in a montane forest of the Yungas ecoregion (according to Ibisch et al. 2003) between the Santa Rosa River and the Wayna sector. The site is well preserved, with a primary forest reached by foot after a 3-day hike. There are a few clearings due to historic human activity because decades ago, this area connected the Mojos and Apolo cantons (Wallace et al. 2019).

Understory mist-nets were used to capture bats for 10 nights (10 mist-nets of 6, 9, and 12 m placed 1 m from the ground), and the total effort employed in this site was 7453 $m^2 \cdot h$ (calculated as mist-net area multiplied by the number of hours they were open). The specimen was collected following the guidelines by Sikes et al. (2016) and under the government research permit MMAYANMABCCGDF/DGBAP/UVSAP No. 354/2015. We extracted the skull, stored the specimen in alcohol, and deposited at the Colección Boliviana de Fauna (CBF) in La Paz, Bolivia.

Preliminary specimen identification was carried out in the field and later confirmed in the lab, with the cleaned skull, following the redescription of the species by Hurtado et al. (2014). We recorded length measurements, weight, age, and reproductive condition while in the field, and skull measurements in the lab. Forearm length and skull measurements were taken with digital calipers (Mitutoyo, Japan) to the nearest 0.01 mm, following Lira et al. (1994) and Hurtado et al. (2014). Other body measurements were taken with a metallic ruler, and weight was taken with a spring scale (Pesola, Switzerland). Age was determined qualitatively by trans-illuminating the wing and observing the epiphyseal growth plate cartilage of the long phalanges of the fifth finger (Brunet-Rossinni and Wilkinson 2009).

The acronyms of scientific collections cited here are as follows: AMNH - American Museum of Natural History; CBF - Colección Boliviana de Fauna; LSUMZ - Louisiana State University Museum of Natural Science; MHNUC - Museo de Historia Natural Universidad del Cauca; and MUSM - Museo de Historia Natural Universidad Nacional Mayor de San Marcos. Specimen and locality information of other records of *G. koepckeae* was obtained from published literature and VertNet (http://portal.vertnet.org), particularly to confirm the coordinates and elevation for Estera Ruana, Peru (Fig. 1). There are two coordinates reported for this locality in VertNet, one that was estimated for specimen LSUMZ 15676 and verbatim coordinates obtained from the catalogue scan of specimen AMNH 233222; we used the latter.

Results

New record. BOLIVIA • 1 ♂ adult; La Paz Department, Franz Tamayo Province, Parque Nacional y Área Natural de Manejo Integrado Madidi, Cargadero; 14°34.68′S, 068°58.81′W; alt. ca 2280 m; 30 Sep. 2016; L. Siles leg.; montane forest; mist net; CBF 8683 (Fig. 2).

Identification. We identified the specimen in the field using the keys for South American phyllostomine species (Williams and Genoways 2008). In the lab, we corroborated the identification with the clean skull, and all diagnostic characters coincided: golden brown pelage color, absent dorsal stripe, crenulated noseleaf sparsely fringed with short fine hairs, small skull, narrow auditory bullae, first and second upper molars with narrow and well-defined vertical groove separating protocone and hypocone (Fig. 2). The only species it can be confused with is *G. crenulatum* because both have crenulated hairy noseleaf, forearm length shorter than 51 mm, and skull length shorter than 25 mm. However, *G. crenulatum* is differentiated by the presence of a dorsal stripe, longer palatal length, wider auditory bullae, and the absence of a vertical groove between the protocone and hypocone on the lingual cingulum of M1 and M2.

Furthermore, *G. crenulatum* is a lowland species (Hurtado et al. 2014; Solari 2019) and the specimen we collected from Cargadero was at an elevation of 2280 m (Fig. 1), which is the highest elevation reported for *G. koepckeae* to date. The external measurements of our specimen are within the range of *G. koepckeae*, except for ear length, which is slightly larger (Table 1). Cranial length measurements are also within the range, but several breadth measurements (postorbital, braincase, mastoid, M1–M1, and M2–M2) are slightly larger (Table 1), rendering a more robust form to the skull (Fig. 2). Diagnostic cranial measurements are the palatal length and auditory bulla breadth (Hurtado et al. 2014), and, in both cases, our specimen's measurements are within the range of *G. koepckeae* (Table 1).

Remarks. The specimen weighed 14 g and showed external testes; it was captured at 19:15 in an understory mist-net located near a small creek. The night of capture was cloudy, not windy, and light rain started to fall at approximately 22:00, which was expected weather because the survey was carried out during the transition between dry

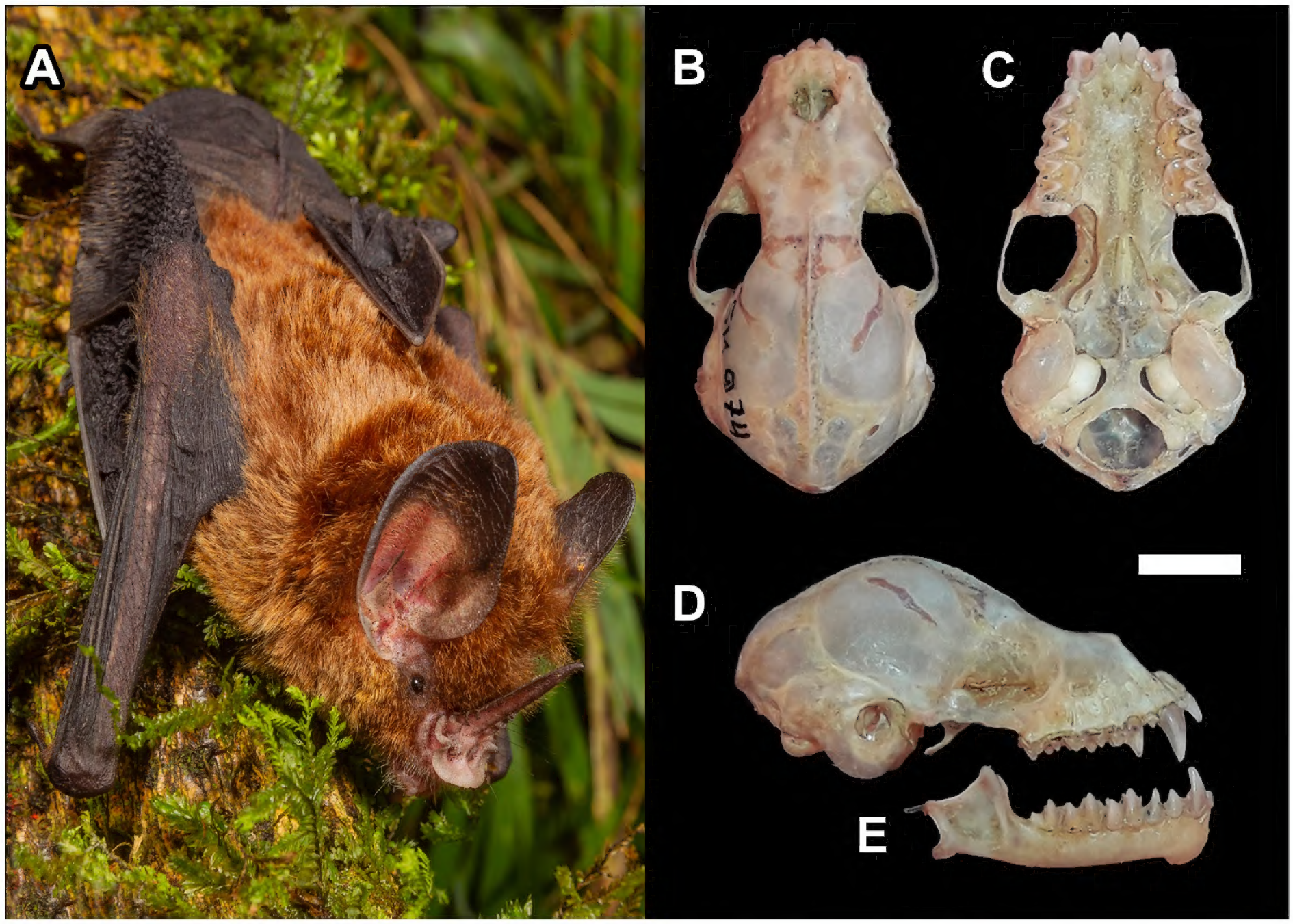

Figure 2. New Bolivian record of *Gardnerycteris koepckeae* CBF 8683. **A.** Live bat (photo credit Mileniusz Spanowicz SERNAP/WCS). **B.** Skull frontal view. **C.** Skull ventral view. **D.** Skull lateral view. **E.** Mandible. Scale bar = 5 mm for B–E. Photographs of skulls by LS.

Table 1. External and cranial measurements of *Gardnerycteris koepckeae* from Bolivia (this study) in comparison with Colombian (Morales-Martínez et al. 2020) and Peruvian (Hurtado et al. 2014) specimens, and data from a large series of *G. crenulatum* from Peru (Hurtado et al. 2014). Descriptive statistics for Peruvian specimens: mean ± standard deviation (sample size). All measures are in millimeters.

	Gardnerycteris koepckeae			*G. crenulatum*
	Bolivia	**Colombia**	**Peru**	**Peru**
Total length	81	76.82	79.00 ± 1.41 (2)	84.09 ± 3.80 (95)
Tail length	20	21.09	19.50 ± 4.95 (2)	23.26 ± 2.54 (96)
Hind foot length	11	10.57	10.00 ± 1.41 (2)	11.57 ± 1.30 (96)
Ear length	24	22.23	22.50 ± 0.71 (2)	24.03 ± 1.57 (96)
Forearm length	49.96	48.09	47.70 ± 0.42 (2)	48.02 ± 3.39 (96)
Greatest length of skull	21	20.83	21.11 ± 0.74 (3)	21.50 ± 0.68 (92)
Condyle-incisors length	19.38	18.71	18.79 ± 0.21 (3)	19.09 ± 0.61 (91)
Postorbital breadth	4.57	4.02	4.14 ± 0.06 (3)	4.26 ± 0.16 (91)
Zygomatic breadth	11.87	11.25	11.67 ± 0.24 (3)	12.13 ± 0.46 (90)
Braincase breadth	8.84	8.35	8.41 ± 0.06 (2)	8.71 ± 0.38 (91)
Mastoid breadth	11.38	10.48	9.92 ± 0.86 (3)	9.70 ± 0.35 (92)
Palatal length	8.44	7.62	8.44 ± 0.33 (3)	9.70 ± 0.40 (92)
Width at M1–M1	7.89	7.33	7.43 ± 0.18 (2)	7.59 ± 0.28 (92)
Width at M2–M2	8.55	8.17	8.04 ± 0.19 (3)	8.26 ± 0.30 (92)
Auditory bulla breadth	2.19	2.30	2.36 ± 0.19 (2)	2.75 ± 0.14 (91)
Maxillary toothrow length	7.86	7.80	7.71 ± 0.36 (3)	7.88 ± 0.23 (92)
Coronoid height	4.23	—	4.46 ± 0.17 (2)	4.39 ± 0.25 (91)
Dentary length	14.14	—	13.47 ± 0.38 (3)	13.89 ± 0.50 (91)
Mandibular toothrow length	8.42	—	8.69 ± 0.06 (2)	8.94 ± 0.27 (91)

and rainy seasons (Arteaga 2007). Other bats captured at the same locality during this survey were: *Carollia brevicauda* (Schinz, 1821), *C. manu* Pacheco, Solari, & Velazco, 2004, *Myotis keaysi* J. A. Allen, 1914, *M. nigricans* (Schinz, 1821), *Platyrrhinus masu* Velazco, 2005, *P. umbratus* (Lyon, 1902), *Sturnira erythromos* (Tschudi, 1844), *S. magna* de la Torre, 1966, and *S. oporaphilum* (Tschudi, 1844).

Discussion

In Bolivia, *Gardnerycteris koepckeae* can only be confused with *G. crenulatum*, which is considered a lowland species (Solari 2019). There are two sources of Bolivian published records for *G. crenulatum* (Anderson 1997; Terán 2010), but we found an error in Terán's (2010) data. Terán (2010) reported several individuals of *G. crenulatum* in La Paz, which included a photographic record by one of us (LS) from the locality Bajo Inicua. The latitude provided by Terán (2010) was not correct, leading to an overestimation of the elevation in this locality (1455 m). The accurate coordinates are 15°17′51″S, 067°26′44″W, and the correct elevation is 330 m. Therefore, *G. crenulatum* has an elevation range of 139–330 m in Bolivia (Anderson 1997; LS unpublished data 2007), confirmed with the elevation range of other specimens in museum collections. In Peru, the distribution for this species ranges from 300 to 900 m (Hurtado et al. 2014), while *G. koepckeae* occurs at a higher elevation (1080–2280 m; Morales-Martínez et al. 2020; this study). Therefore, the two species can be sympatric along the 1000 m line, at least in Peru.

Gardnerycteris koepckeae was described as a very rare species, endemic to Peru, known from the type locality, its surroundings in Ayacucho Department (alt. 1660 m), and from a specimen collected in Junin Department (alt. 1890 m) 40 years later (Hurtado et al. 2014). More recently, an unexpected record from an adjacent habitat in Colombia, Department of Caquetá (alt. 1080 m) extended the distribution 1400 km further north (Morales-Martínez et al. 2020). The record in Bolivia expands the distribution of this species 558 km south-southeast from the type locality (the closest point, Fig. 1), and the altitudinal limit from 1900 to 2280 m. This remarkable and recent distribution extension opens the possibility of finding more records, particularly in northern Peru and Ecuador, as well in similar montane habitats in central Bolivia.

Furthermore, we observed morphological differences that may be worth exploring. For instance, the skull shape, particularly in the Bolivian specimen, is more robust in the postorbital region (Fig. 2B). As for the Colombian and Peruvian specimens, despite their similar skull, a cytochrome-b analysis yielded a 2.9% divergence between these specimens using the Kimura 2-parameter model (Morales-Martínez et al. 2020). The authors use this value to confirm the identification because it is consistent with intraspecific variation for several phyllostomid species (Bradley and Baker 2001). However, based on more recent data, Velazco and Lim (2014) consider that values ≥2% do separate valid species in the family, and examples in the lower range can be found in *Platyrrhinus* Saussure, 1860 (Velazco and Patterson 2008), *Micronycteris* Gray, 1866 (Larsen et al. 2011), and *Sturnira* Gray, 1842 (Velazco and Patterson 2013). Although we were not able to sequence our specimen yet, when further data is gathered for *G. koepckeae*, it will be interesting to analyze genetic and morphological variations across its distribution.

Hurtado et al. (2014) argued that the few records reported for *G. koepckeae* might reflect the lack of sampling in montane forest, but we disagree because fieldwork carried out in Bolivia has not resulted in more specimens. Examples of bat surveys at the Yungas ecoregion in the last 15 years include: 1) short 5-night evaluations carried out by one of us at two localities at 900 and 2070 m, with 13 and 8 phyllostomid species captured in each site, respectively (LS unpublished data, 2005-6); 2) a 4-month survey at approximately 1400 m with 17 phyllostomid species reported by Montaño-Centellas et al. (2015); 3) a 2-year project carried out between 1400 and 1650 m by Moya et al. (2008), which reported 20 phyllostomid species. Also, in Identidad Madidi we surveyed 3 additional Yungas sites at 1870, 1600, and 1160 m for a total of 23 nights, which yielded 6, 14, and 19 phyllostomid species, respectively (Wallace et al. 2017; Wallace et al. 2019; Wallace et al. 2020). Following the criteria outlined by Yu and Dobson (2000), due to its probable low population size (three specimens in three countries reported from 2011 to 2016), narrow habitat, and patchy distribution range, *G. koepckeae* can be considered rare. Therefore, we confirm the rarity of *G. koepckeae*, at least in Bolivia, with a distribution restricted to preserved low Andean montane forest, an extremely speciose and fragile ecosystem, threatened by climate change and human disturbance (Ibisch and Mérida 2003; Ministerio de Medio Ambiente y Agua 2009). All this information must be considered to update the Bolivian and regional conservation status of this species.

Acknowledgements

The Wildlife Conservation Society and the Gordon and Betty Moore Foundation financed the Identidad Madidi initiative. The National Protected Area Service of Bolivia (SERNAP) and Madidi National Park and Natural Area of Integrated Management (PNANMI Madidi) provided logistical support. The Plurinational State of Bolivia provided research and collecting permits. We thank local communities 3 de Mayo and Puina for their help and for providing field guides. We also thank the Identidad Madidi logistics team, who organized the fieldwork, as well as the bat team Marisol Hidalgo (MHN Alcide d'Orbigny) and Justiniano Flores (Puina). We thank Marcelo Nogueira, Natalí Hurtado, and Héctor Ramírez-Chaves for providing helpful comments that improved this manuscript.

Authors' Contributions

LS carried out the bat fieldwork, specimen identification, and specimen measurements. RBW designed the Identidad Madidi project, developed funding streams for the initiative, organized field trips, and applied for collecting and research permits. Both authors prepared and edited the manuscript.

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